WAVE HINOCASTS ANO MEASUREMENTS BASS STRAIT

By

M. N. Silbert*, T. P. Barnett**, O. J. H. Peters† and R. C. Hamilton††

1.0 INTROOUCTION

The Bass Strait of Australia is the location of significant offshore oil and gas production. At the time of this writing eight self-contained drilling and production platforms as well as many miles of submerged pipeline comprise the Esso Australia Ltd. (EAL) and Broken Hill Proprietary Company Ltd. (BHP) operation in the Bass Strait. Ouring the course of the next five years significant additional development and platform construction will take place in this offshore oil and gas area.

Observation of offshore wind and wave conditions are greatly facilitated by the presence of fixed platforms from which to collect data. Visual observations of waves along with measurements of wind speed and direction and barometric pressure from Bass Strait Platforms have been routinely recorded and reported to the Australian Bureau of meteorology for more than ten years. Close cooperation between EAL and the Meteorological Bureau has resulted in continuous weather forecasts for the Bass Strait region.

In March of 1977 EAL decided to upgrade the instrumentation on two of the platforms in the Bass Strait. The purpose of this was to reduce the subjectivity of visual wave observations and to eliminate the uncertainty of such observations at night and during inclement weather. Additionally it was felt that by instrumenting both a deep water (250 feet) and a shallow water (150 feet) platform the data collected would help quantify the observation that the storm waves seemed to be larger in deeper water than in shallow water. It was felt that use of the data along with a computer based wave hindcast model would aid in the development of an understanding of the Bass Strait wave environment.

Two platforms were chosen for instrumentation. The Barracouta (BTA) platform in 150 feet of water, located about 20 miles from shore, was instrumented with a wavestaff. The Kingfish B (KFB) platform in 250 feet of water, located about 50 miles southeast of BTA, was instrumented with a wave staff, electromagnetic current meters, anemometer, barometer and air temperature sensor. Figure 1 shows the location of these platforms in the Bass Strait. The design, fabrication and installation of the data station was performed by Evans-Hamilton Inc. of Houston, Texas.

*Exxon Production Research Company, Houston, Texas
**Scripps Institute of Oceanography, La Jolla, California
†Oceanographic Services, Inc., Santa Barbara, California
††Evans-Hamilton, Inc., Houston, Texas

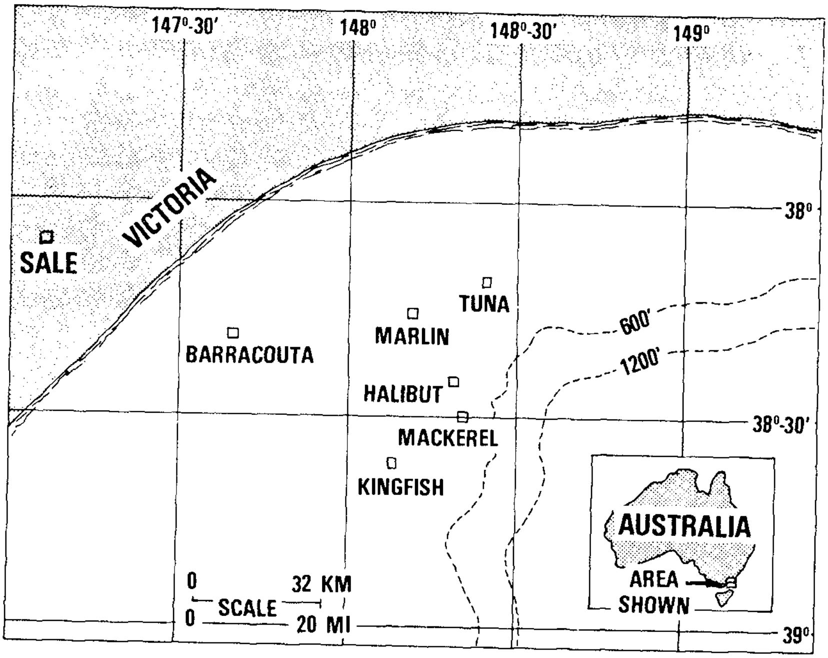


Figure 1. Bass Strait location map

Section 2 of this paper provides an overall summary of the Bass Strait weather. This is followed, in Section 3, by a review of the data acquired in the Bass Strait through the first six months of 1978. The wave hindcast model used is described in Section 4. Comparisons between measured and predicted sea conditions are detailed in Section 5.

2.0 AN OVERVIEW OF BASS STRAIT WEATHER AND WAVE CONDITIONS

During most of the year, the general atmospheric circulation in the region surrounding Tasmania and southeast Australia can be characterized as a steady procession of anticyclones moving from west to east with intervening troughs of low pressure. These troughs are usually accompanied by unsettled weather which often lasts for several days.

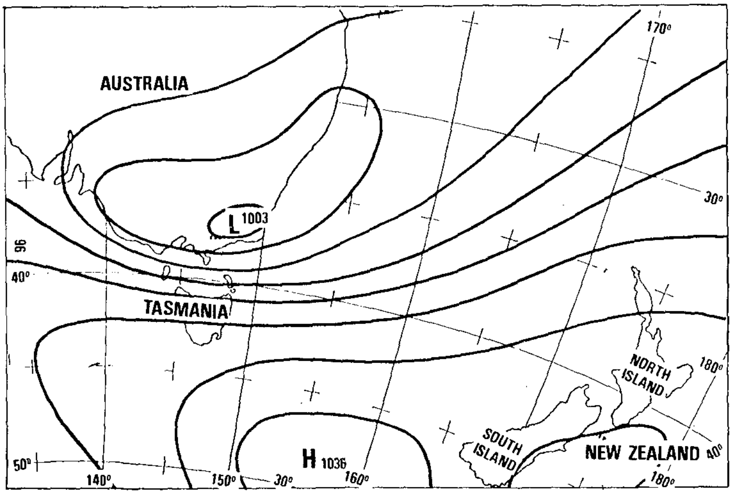
Low pressure systems track eastward across the southern Indian Ocean, south of 50° south latitude. Cold or occluded fronts associated with these systems usually extend northwestward from the storm center and track rapidly eastward through the Bass Strait region. Secondary low centers often form along these trailing fronts and move eastward or southeastward toward New Zealand. There are two favored areas for the formation of the secondary low centers: (1) the Great Australian Bight, and (2) the western Tasman Sea. On rare occasions one of these low centers will intensify enough to generate very strong wind ($\geq$ 50 knots) in the Bass Strait. These storm events can be classified in one of three categories: (1) southwest storms, (2) southeast storms, and (3) southeast/southwest storms.

When intense cold fronts approach the Bass Strait, prefrontal winds blow from the northwest. Immediately after frontal passage, the wind direction shifts to the southwest, with strong wind speeds accompanied by high seas. The most intense southwest storms can generate winds as high as 50 to 60 knots.

The second class of severe storms are those that traverse or develop in the Tasman Sea. As these systems move into the central portion of Tasman Sea, they generate strong east to southeast winds (up to 60 knots).

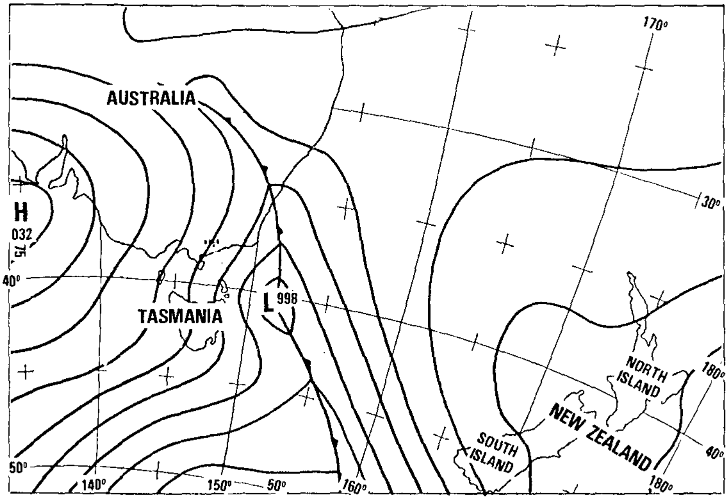
Typical surface synoptic chart representations of these two types of storms are presented in Figures 2a and b. Note the classical closed circulation of the southeast storm (2a) typical of large extra-tropical storms. The southwest storm (2b) on the other hand presents a more complicated synoptic situation.

The final class of severe storms is similar to the southeast type. That is, they develop in or traverse the Tasman Sea. However, at some point near the peak (highest wind speeds) of the storm, a trough forms in the Bass Strait, generating south to southwest winds (waves) throughout most of the Strait. At the same time, very strong southeast winds are present just outside of the Bass Strait, extending well into the



HL NUMBERS INDICATE CENTRAL PRESSURE IN MILLIBARS

Figure 2a. Typical Southeast Storm



HL NUMBERS INDICATE CENTRAL PRESSURE IN MILLIBARS

Figure 2b. Typical Southwest Storm

Tasman Sea. These southeast winds generate waves that propagate into the Bass Strait from the southeast.

3.0 SUMMARY OF OATA COLLECTEO

Both data stations were made operational in early January of 197B. Since that time a large amount of "operational" (day-to-day normal conditions) data have been gathered. While these data are of great interest, the remainder of this paper will only discuss data collected during storms and the modeling of these storms.

3.1 STORM OATA (WINO ANO WAVES)

During the period between January 1978 and June 1978, four storms occurred which were suitable for our analysis. Three of these storms were "southeasters" and one was a "southwester". Maximum significant wave heights ranged between 13.5 feet at BTA during a southwest storm in Feburary to 29 feet at KFB during a June storm. For the sake of brevity we will present details of only two of these storms. However model comparisons have been made, and they will be discussed for all four storms.

3.1.1 SOUTHEAST STORM: Jan. 27-29, 197B

This storm developed on the east coast of Australia near 33°S latitude. The storm tracked to the southwest across Bass Strait and then southeast across the Tasman Sea. Maximum sustained wind speeds of 40 kts and largest significant wave heights of 21 feet were noted.

The measured H_s vs. time during this storm is shown in Figure 3a for the KFB location and in Figure 3b for the BTA location. Plots showing the measured average zero crossing wave period vs. time for KFB and BTA are shown in Figures 4a and b. The measured wind speed vs. time at KFB is shown in Figure 5.

3.1.2 SOUTHEAST STORM: JUNE 1-4, 1978

Initial development occurred over the interior of Australia near 2B°S latitude, 147°E longitude. The storm moved off the east coast of Australia and tracked south near Bass Strait. It then moved east across the Tasman Sea. Maximum sustained winds reached 50 kts and significant wave heights as high as 29 feet were measured. A single zero crossing wave in excess of 60 feet was measured at KFB.

Significant wave height (H_s) time history plots for this storm are shown in Figure 6a and b for KFB and BTA respectively. Zero crossing period plots are shown in Figure 7a and b. Measured wind speed and direction vs time are shown in Figure 8a and b for the KFB location.

As shown in Figures 7-8, for some reason the KFB data station was not recording for a 10 hour period during this storm.

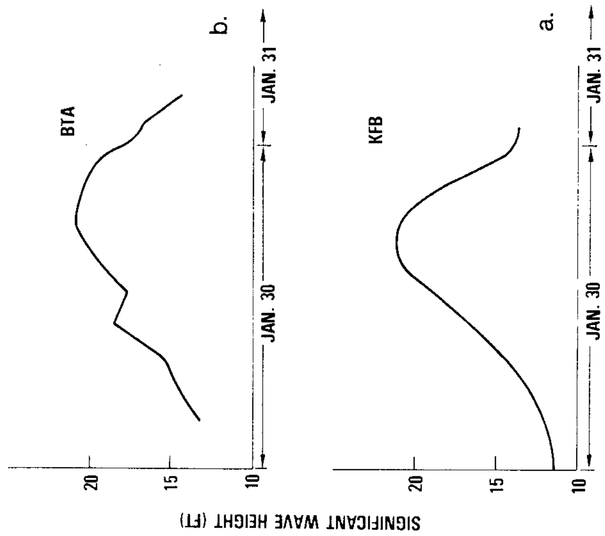


Figure 3. Storm Sea States—Jan. 1978

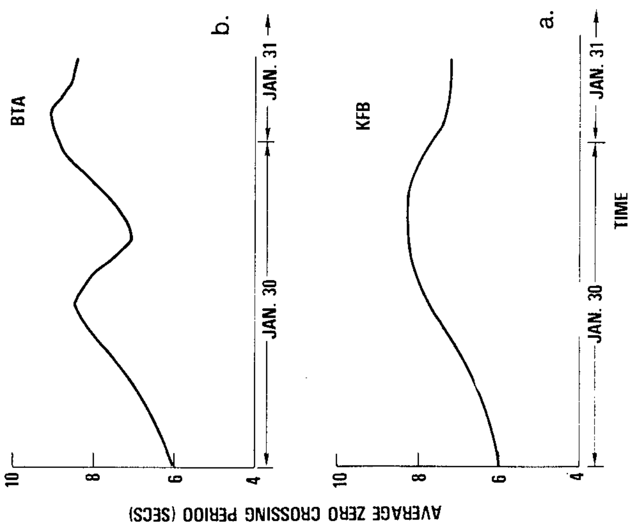


Figure 4. Wave Periods—Jan. 1978

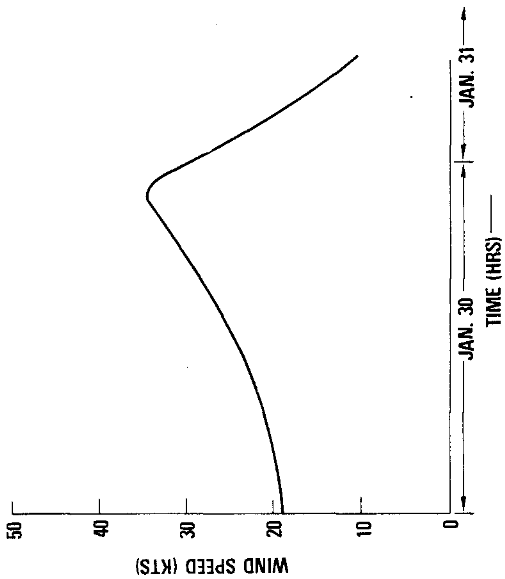


Figure 5. Wind Speed at KFB—Jan. 1978

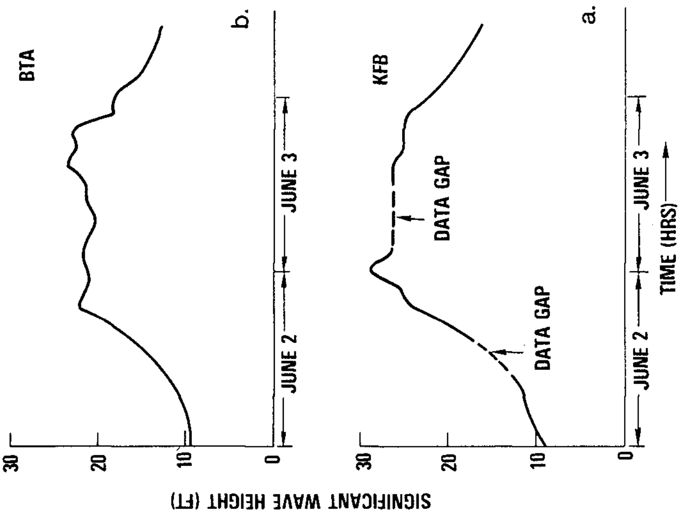


Figure 6. Storm Sea States—June 1978

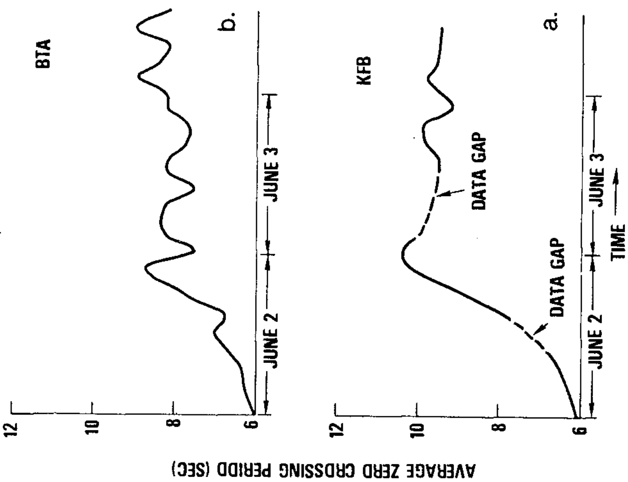


Figure 7. Wave Periods—June 1978

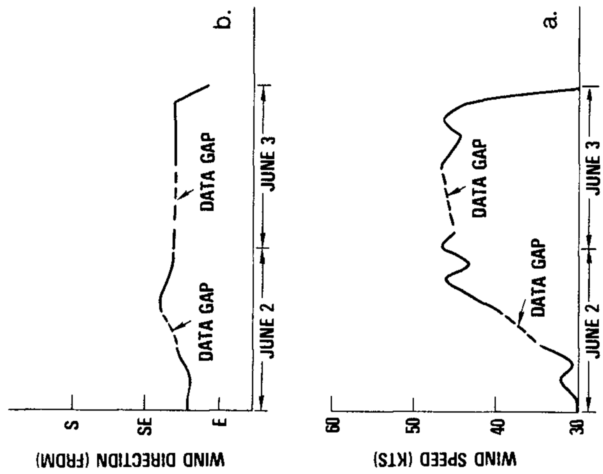


Figure 8. Wind Data—June 1978

3.2 CURRENT DATA

One of the original goals of the instrumentation installed on KFB was to obtain data from the electromagnetic current meters that would enable determination of a directional wave spectrum. Due to various problems with the current meters and their mountings this goal was not achieved during the storms mentioned above.

4.0 DESCRIPTION OF THE WAVE HINDCAST MODEL

We approach hindcasting the storms described above in two steps. First we treat the general problem of the generation of waves by wind in deep water. The wave model used in this part of the study was a spectral model based on the equation of radiative transfer (Barnett, 1968; Barnett, et al, 1969). In this model, propagation of wave energy is accounted for by the method of characteristics and is highly accurate numerically. Wave growth and decay are accounted for by atmospheric source terms that are based on theory (Miles, Phillips) and on empirical fits of observed wave generation cases. The wave-wave interaction terms are parameterized from the theoretical results of Hasselmann. The dissipation in deepwater is partially empirical and partially theoretical, relying on the concept of an equilibrium range in the high frequency portion of the spectrum.

The model is easily adjustable to arbitrary grids in physical space, as well as frequency-direction space. Thus it has been easy to test the model in both open ocean environments (e.g., North Atlantic, North Pacific) and enclosed bodies of water (South China Sea, Lake Superior) against actual observation. In all cases the average significant wave height hindcast error has been less than 3 feet rms. Recently the model has been applied to several storms in the North Sea with notable success in comparison with measured wave data.

The second step in our modeling procedure was to account for effects due to the interaction between the waves and the sea bottom. We have used a model based on the work of Hasselman and Collins (1968) to account for wave energy dissipation due to interaction with the sea bottom. This model does not account for shallow water generation, nor does it consider other forms of dissipation. It does provide an order of magnitude estimate of energy loss. Results of the dissipation calculations along with the difference between the results of the deepwater modeling at both KFB and BTA are used to estimate the wave energy at BTA.

4.1 WIND FIELD SPECIFICATION

Three basic marine wind field analysis methods are available for use in hindcasting severe storms:

a. parametric wind models
b. objective analysis schemes
c. manual wind field analysis

Parametric models have been utilized (with considerable success) in modeling the surface wind field associated with tropical cyclones. However, these models have not been successfully applied to the complex wind fields associated with severe extratropical cyclones (Bretschneider, 1972).

Various objective analysis schemes are available for use in the specification of surface marine wind fields. These schemes range from computer-based routines that utilize surface pressure fields and marine wind observations, to complex planetary boundary layer (PBL) models that relate the surface pressure gradient, air-sea temperature difference and thermal advection to the local wind speed and direction (see Overland and Gemmill, 1977; Mooers and Partagas, 1976; Druyan, 1973, 1972; and Cardone, 1969). Provided a reasonably dense network of marine observations is available, the objective analysis schemes will yield results suitable for use in hindcasting severe extratropical storms.

The third analysis method (c above) is a technique in which experienced meteorologists derive the surface wind field distribution based on manually analyzed surface pressure fields and available marine wind observations. Although this method is very time consuming and therefore costly, a skilled, patient, meteorologist can produce very accurate results. The manual method has obvious advantages in that questionable data can be screened out more effectively, and observations not recorded at synoptic time periods can be easily incorporated into the evaluation.

4.1.1 DATA BASE

The marine areas surrounding Australia, Tasmania and New Zealand (like most marine areas) can be characterized as data sparse regions, where surface pressure analyses are based on a very limited number of ship observations. On the average, there are only 3 or 4 marine observations contained on the Australian Weather Service charts over the entire area of interest both east and west of the Bass Strait. Therefore, it was decided that the manual wind field analysis method would be the most appropriate technique to use in this hindcast, as it would provide the most accurate input data.

The Australian maps were reanalyzed OSI (Oceanographic Services Inc.) meteorologists based on: 1) additional observational data derived in a data search (through the National Climatic Center in Asheville North Carolina), and 2) prior experience in analyzing marine wind fields for the purpose of wave hindcasting in all areas of the world. In many cases existing historical surface pressure analyses can be improved by reanalysis, thereby improving the accuracy of hindcast wind fields.

4.1.2 SELECTION OF WIND SPEEDS AND DIRECTIONS

An appropriate grid system was developed for each storm type analyzed. Grid points were densely spaced within the Bass Strait with spacing increasing outside the Bass Strait. The grid system was designed so that all regions of potential wave generation could be covered.

Hindcast wind speeds (10-minute average, 10-meter/standard level) and directions were derived at each grid point from horizontal pressure gradients, as reanalyzed from the Australian maps. Wind observations, recorded by ships operating in the basins during the hindcast time periods (acquired from the National Climatic Center) were also used in conjunction with the pressure analyses in selecting wind parameters.

In addition, observations from drilling units, and locally analyzed pressure maps (analyzed by OSI meteorologists in Sale, Australia during forecast projects in the Bass Strait) were used by OSI to augment the wind field analysis. During this earlier work, OSI found good correlation between wind speeds for various Bass Strait locations and pressure gradients between selected Australian and Tasmanian coastal stations. These relations were used as initial guidance in selecting wind parameters at grid points in the Bass Strait. OSI's choice of the wind field analysis method made it easier to incorporate these relations into the hindcasting scheme.

Finally, hindcast wind speeds and directions were compared with wind parameters reported at Australian and Tasmanian coastal stations. Reported coastal winds were adjusted to compensate for differing frictional effects as well as observed topographical effects.

The final wind field analyses were derived using all sources of available data. We believe that these analyses were as accurate as possible, within the limitations of the available data.

4.1.3 TIME INTERPOLATION OF WIND SPEEDS AND DIRECTIONS

It was necessary to provide wind input for each time step (one hour) of the model integration. Therefore, wind data were interpolated between available input map times. A linear interpolation scheme (for both wind speed and direction) was chosen as the best approximation for this hindcast after careful analysis of the wind speed time histories recorded at two marine measurement stations in the Bass Strait during the severe storms under consideration.

5.0 COMPARISON BETWEEN MEASURED AND CALCULATED CONDITIONS

To date we have compared calculated conditions with measurements for four storms at two locations. In general the results of this comparison have been very encouraging. Figure 9 shows a summary of the comparison between maximum measured H_s and maximum hindcast H_s. The discrepancy between model and data was unbiased while the rms deviation was less than 3 feet. Comparisons of this type have been reported elsewhere (Cardone et. al. Ewing et. al.) and allow a gross level of agreement to be established.

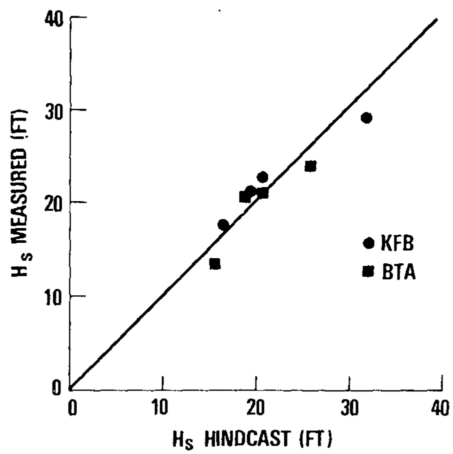


Figure 9. Measured and Calculated Maximum Sea States

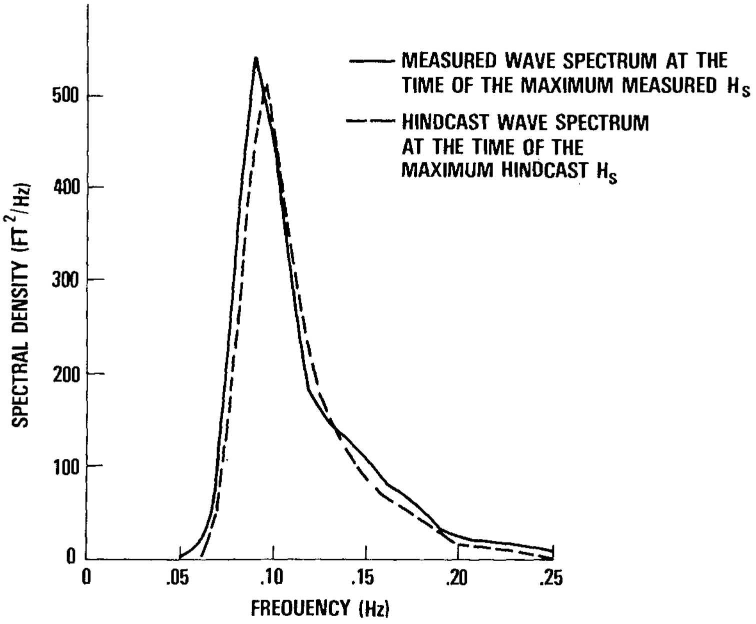


Figure 10. Wave Spectrum Comparison—Jan. 1978

More detailed comparisons between the measured data and the wave model have been made. These comparisons are useful in determining areas in which the modeling process can be improved. A more detailed model comparison for the two storms discussed earlier (January and June 1978) is given below.

5.1 STORM OF JANUARY 1978

During the peak of this storm the maximum measured wind speed at KFB reached 36 kts while the maximum hindcast winds reached 40 kts. The resulting maximum significant wave heights were 21 feet (measured) and 19.5 ft (hindcast) respectively. Figure 10 shows a comparison (for KFB) between the maximum measured and maximum hindcast wave spectra during the peak of this storm. Subjectively this comparison is excellent both in terms of total energy and frequency distribution.

Figure 11 presents a comparison of the sea state intensity (H_s) as the storm passes at KFB. It is clear from this plot that the general character of the storm development has been depicted by the model results. However, Figure 11 also illustrates the fact that there is a several hour shift in the time of occurrence of the peak seas. Given the 6 hour synoptic interval this fact is not surprising. A similar result was obtained at BTA with the agreement between measured and hindcast sea states being even better than it was at KFB. Numerical calculations convinced us that shallow water dissipation would not be evident in a storm of this intensity in these water depths.

5.2 STORM OF JUNE 1978

The results of our comparison of the measured and hindcast storm of June 1978 illustrate several interesting problems that can enter studies such as ours, but which are not usually reported.

5.2.1 DEEP WATER RESULTS

The maximum hindcast significant wave height for this storm at KFB was 32 feet. The maximum measured significant wave height for this storm at KFB was 29 feet (for a 40 minute period). The spectral comparison for this storm is shown in Figure 12. The maximum hindcast windspeed at KFB was 50 kts while the maximum measured wind speed was 46 kts. The wind/wave comparison stated in this way appears extremely good. However, if we look at the overall storm profile of H_s shown in Figure 13, several points become clear:

- The duration of the storm was underestimated
- The buildup of the seas was not reproduced
- The period of sustained high waves for the hindcast storm was substantially different from the measured storm

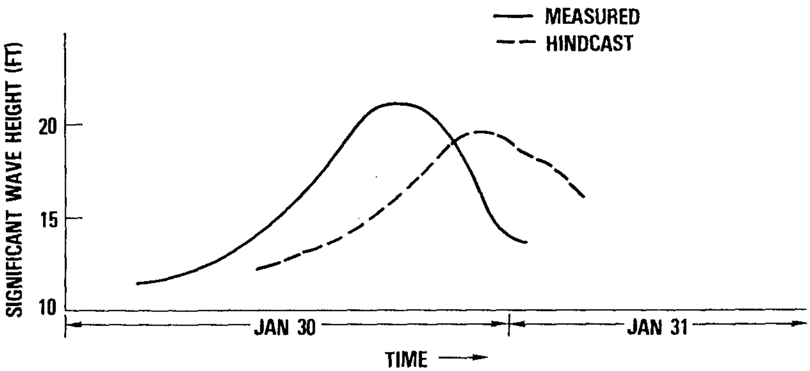


Figure 11. Measured and Hindcast Storm Profiles—Jan. 1978
KFB

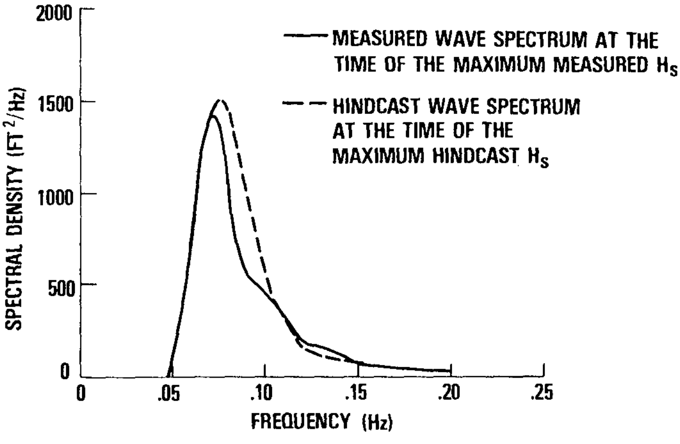


Figure 12. Wave Spectrum Comparison—June 1978

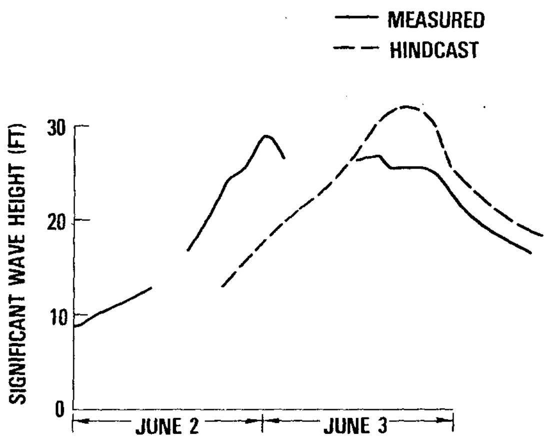


Figure 13. Measured and Calculated Storm Profiles

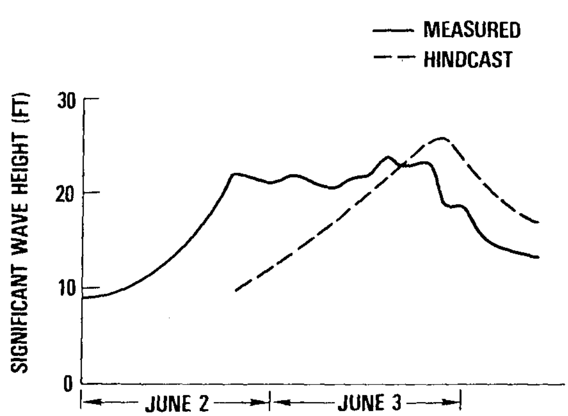


Figure 14. Measured and Calculated Storm Profiles
BTA

The reasons behind the above mentioned shortcomings, in this particular hindcast, can almost certainly be traced to the weather map construction. Due to the fact that the wave hindcast was conducted almost immediately following the construction of the weather charts, there was insufficient time to include any post analysis in this particular hindcast. It is the opinion of the authors that the shortcomings in this case are more indicative of weather forecast limitations than wave model inadequacy.

5.2.2 SHALLOW WATER EFFECTS

As mentioned previously we have used a shallow water computational algorithm to help quantify the reduction in wave intensity between KFB and BTA. The hindcast deepwater spectra at KFB were input to the model and the resulting spectra at BTA were computed. Since the shallow water model did not account for wave energy input from local winds, these computed values were further adjusted (somewhat arbitrarily) by the difference between the "deepwater" values at KFB and BTA. The purpose of this adjustment was to account for the spacial variability in the hindcast wind field in an order-of-magnitude way. In this case the adjustment led to a reduction in the calculated BTA sea intensities of approximately 2 feet. The results of this operation are shown in Figure 14. Once again, the peak sea intensity is reasonably represented by our model but the overall storm characteristics are not well represented. We again believe that the major influence for this storm is the inaccuracy in the weather analysis.

6.0 MODEL COMPARISON CONCLUSIONS

In general we have demonstrated that the numerical hindcast techniques discussed herein can be used to adequately estimate storm sea state characteristics. The model was applied to four storms at two locations yielding estimates of maximum significant wave height that on the average were within 3 feet of the measured values. Detailed comparison of model results with data indicate that the primary limitation in model capability is associated with the windfield description.

Furthermore we have documented the fact that significant differences in sea state intensity can exist between KFB and BTA during large storms with wind and waves from the southeast. Some of this difference can be attributed to bottom dissipation while some can likely be attributed to windfield variations. Additional studies along these lines that quantify the various influences more precisely (Shemdin et al.,) would be worthwhile.

7.0 ACKNOWLEDGEMENTS

The authors would like to thank Henry Gerlach, Ian Edwards and Alan Lunghusen of EAL for their help in this project. We would also like to thank the Royal Australian Navy Research Laboratory for their interest and help in maintaining the equipment. The Australian Bureau of Meteorology is to be thanked for their cooperation in providing synoptic weather charts. Special thanks are directed to R. E. Haring of Exxon Production Research for his help and encouragement during the almost 2 years that this project spanned.

REFERENCES

1. 8arnett, T. P., 1968, "On the Generation, Dissipation, and Prediction of Ocean Wind Waves," Journal of Geophysical Research, Vol. 73, pp. 513-530.

2. Barnett, T. P., C. H. Holland, and P. Yager, 1969: "A General Technique for Wind Wave Prediction with Application to the South China Sea," Final Report Contract N62306-68-C-0285, Westinghouse Research Laboratories, 31pp.

3. 8retschneider, C., 1972: "A Non-Dimensional Stationary Hurricane Wave Model, "Offshore Technology Conference, Paper OTC 1517, pp. I-51-I-68.

4. Cardone, V., 1969: "Specification of the Wind Distribution in the Marine 8oundary Layer for Wave Forecasting," GSL Report TR-69-1, Oept. of Meteorrology and Oceanography, New York University.

5. Oruyan, L., 1973: "Objective Sea-Level Pressure Analysis for Oata-Sparse Areas," Journal of Applied Meteorology, Vol. 12, pp. 256-263.

6. Oruyan, L., 1972: "Objective Analysis of Sea-Level Winds and Pressures Derived from Simulated Observations of a Satellite Radar-Radiometer and Actual Conventional Oata," Journal of Applied Meteorology, Vol. 11, pp. 413-428.

7. Ewing, J. A., Weare, T. J. and Worthington, 8. A.: "A Hindcast Study of Wave Climate in the Northern North Sea", EUR 10, European Offshore Petroleum Conference and Exhibition, October 24-27, 1978, London.

8. Hasselman, K. and Collins, J. I. 1968: "Spectral Oissipation of Finite Oepth Gravity Waves Oue to Turbulent Bottom Friction," Journal of Marine Research, Vol. 26, pp 1-12.

9. Miles, J. W., 1957: "On the Generation of Surface Waves by Shear Flows. Part I, "Journal of Fluid Mechanics, Vol. 3, pp. 185-204.

10. Mooers, C., and J. Partagas, 197? "Meteorological Forcing Fields in the New York Bight," Technical Report, University of Miami, Rosentiel School of Marine and Atmosphere Science, 117 pp.

11. Overland, J., and W. Gemmill, 1977: "Prediction of Marine Winds in the New York Bight," Monthly Weather Review, Vol. 105, pp. 1003-1008.

12. Phillips, O. M., 1977: "The Dynamics of the Upper Ocean", Cambridge University Press.

13. Shemdin, O. H., Hasselmann, K., Hsiao, S. V., and Herterich, K., 1977: "Nonlinear and Linear Bottom Interaction Effects in Shallow Water," Nato Symposium on Turbulent Fluxes Through the Sea Surface, Wave Dynamics and Prediction," Marseille, France.

14. van Loon, H., J. J. Taljaard, T. Sasamori, J. London, D. V. Hoyt, K. Labitzke, and C. W. Newton, 1972: "Meteorology of the Southern Hemisphere," Meteorological Monographs, Vol. 13, No. 5, 263 pp.

15. Ward, E. G., Borgman, L. E. and Cardone, V. J.: "Statistics of Hurricane Waves in the Gulf of Mexico," OCT 3229, 10th Offshore Technology Conference, May 8-11, 1978, Houston, Texas.